Energy Savinator 6000: An IoT-Driven Adaptive Room Control System with Multi-Sensor Integration

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***Abstract*—The demand for energy continues to rise significantly over time. Inflation, the escalating cost of energy, and a constrained supply have resulted in substantial increases in electricity prices. Furthermore, power grids and household-level transformers have ratings; exceeding these can lead to grid failures and transformer overloads. Individual households can benefit from systems designed to reduce electricity consumption, provided that 1) these systems do not compromise daily comfort and convenience, and 2) they offer a return on investment through energy savings. This project entailed the development of an electronically fundamental, stripped-down system using only two ATMEGA 328P microcontroller units. The proposed system autonomously regulates HVAC and lighting based on sensor data inputs. Control actions are executed via relay modules. The prototype was deployed in a controlled environment simulating a standard room layout to validate the potential energy savings generated.**

***Index Terms*—smart home, energy savings, IoT control system**

I. Motivation

The Earth's resources are undeniably finite, yet an ever-growing global population continues to consume these resources at an unprecedented rate. With each passing day and each new individual added to the population, the demand for electrical power continues to escalate.

Current methods of power generation are inherently inefficient, with conversion efficiency rates ranging from approximately 1% at renewable binary geothermal plants [1] to about 45% at non-renewable ultra-supercritical coal plants [2]. Furthermore, the U.S. Energy Information Administration (EIA) reports that an average of 5% of generated power is lost during transmission and distribution [3]. Despite these systemic inefficiencies, inactive devices—appliances that draw power while not in active use—account for approximately 3% of household electricity consumption in Switzerland and up to 11.6% in Australia [4]. Compounding all this, a study conducted by the U.S. Department of Energy in collaboration with UC Berkeley estimates that nearly 68% of all energy is lost from generation to end use [5]. These inefficiencies add much unnecessary stress on the system and further drive up the cost of energy, both environmental and monetary.

This project, the 'Energy Savinator 6000', optimises electricity consumption at the household level. The system is designed to be scalable, extending its applications to commercial spaces as well. The Energy Savinator 6000 utilises an extensive array of sensors, including ultrasonic, temperature, gas, pollutant, and proximity infrared (PIR) sensors. These sensors feed data into dual ATMEGA 328P microcontroller units operating in parallel computation. The system utilises these inputs to dynamically determine the occupancy and environmental conditions of a given room. Based on this real-time data, it optimises the operation of HVAC systems and lighting to achieve maximum power efficiency while maintaining optimal comfort levels for occupants.

The aggregation of the energy savings delivered by such a system to thousands of households should lead to a substantial reduction in energy consumption on a national level, thereby decreasing pollution levels and lowering electricity bills for all, further stimulating the economy [6]. This, in turn, would increase disposable income and lower levels of pollution, contributing to an overall better standard of living. In fact, every dollar invested in reducing carbon emissions is estimated to yield nine dollars in public health benefits and consumer savings [7].

II. Review of existing solutions

A. Heating, Ventilation & Air Conditioning (HVAC)

Recent advancements in smart home technologies have significantly enhanced residential comfort, energy efficiency, and indoor air quality [8]. Smart thermostats offer the same functionality that this project aims to offer, in part or in whole. They provide advanced functionalities for comprehensive HVAC management, particularly in optimising temperature control, and are typically integrated by connecting directly to the centralised heating or cooling system, after which they autonomously manage thermal regulation. They enhance energy efficiency by automatically deactivating the heating or cooling systems once the desired temperature is achieved, and some models extend their capabilities by addressing thermal imbalances within individual rooms. While this project culminated in the development of an electronically minimal system, it started out as a competitor to such existing connected systems.

According to Delaney and Greenwald [9], the Ecobee Smart Thermostat, Google Nest Learning Thermostat, Honeywell Home T9, and Sensi Touch 2 Smart Thermostat rep-

resent some of the most advanced and widely adopted smart thermostats currently available in the commercial merket.

The Ecobee Smart Thermostat stands out for its deep integration capabilities with platforms such as Amazon Alexa, Apple HomeKit, and SmartThings, making it highly adaptable for smart home environments, with key features including integrated voice control, smart occupancy sensors, and real-time energy usage reporting via the Ecobee app [10]. These functionalities enable dynamic temperature management by adjusting settings based on room occupancy, thus effectively reducing thermal imbalances across different zones. However, the Ecobee's higher initial cost, installation complexities—particularly in HVAC systems without a common (C) wire—and reliance on internet connectivity for optimal performance are significant drawbacks [11].

In contrast, the Google Nest Learning Thermostat leverages advanced machine learning algorithms to provide a more personalised climate control experience, automatically adjusting temperature settings based on observed user behaviour and historical preferences [12]. The Nest's key functions, including auto-scheduling and Home/Away Assist, use occupancy sensors and geofencing to optimise energy consumption efficiently, while its compatibility with Google Assistant, Amazon Alexa, and other smart home platforms enhances its versatility [13]. Nonetheless, the Nest Learning Thermostat's relatively high cost, limited flexibility in manual scheduling, and potential compatibility issues with older HVAC systems pose challenges to potential buyers.

The Honeywell Home T9 Smart Thermostat presents a balanced approach, offering a mix of advanced smart functionalities and a user-friendly design, with smart room sensors that monitor temperature, humidity, and occupancy, enabling precise multi-zone climate control [14]. The T9 is compatible with all major smart home ecosystems and provides customisable alerts for extreme temperature and humidity conditions. However, the T9's reliance on Wi-Fi connectivity for remote operations and its incompatibility with certain multi-stage systems limit its suitability in specific environments.

The Sensi Touch 2 Smart Thermostat ST76, meanwhile, offers a more budget-friendly option, delivering essential smart thermostat functionalities like a colour touchscreen, remote control via the Sensi app, and smart alerts for system anomalies [15]. It is also compatible with most smart home ecosystems, making it flexible for basic smart home integration. However, the ST76 lacks the advanced machine learning capabilities found in the more premium models and offers limited customisation options. Its relatively bulky design and less intuitive user interface also detracts from its overall appeal.

A significant limitation affecting the deployment of these advanced smart thermostat systems in countries such as India is their requirement for a centralised HVAC infrastructure. In many developing nations, residential buildings predominantly utilise 'mini-split air conditioning units', which are decentralised systems comprising an outdoor compressor and one or more indoor air-handling units [16]. To illustrate, in India, Voltas, a leading manufacturer of residential air conditioning solutions, reported a 35% increase in the sale of compressor-based mini-split systems, with total sales exceeding 2 million units across all product categories [17]. This sales trend highlights the widespread adoption of decentralised air conditioning systems within the country, which are not compatible with the smart thermostats discussed thus far.

Consequently, it is evident that any smart home automation system aimed at reducing energy consumption and costs by optimising HVAC operation in India (and other developing nations) must be capable of interfacing with and controlling decentralised systems. Therefore, this project was then reimagined to enable efficient and easy integration with such decentralised systems.

However, while fewer in number, there are some smart thermostats designed to work with individual HVAC units, including the Cielo Breez Plus and the Sensibo Smart AC Controller. Both represent advanced retrofit solutions for enhancing traditional air conditioning systems with smart capabilities. The Cielo Breez Plus is notable for its extensive functionality, offering remote operation via a mobile application, intelligent scheduling, geo-fencing, and detailed energy consumption monitoring. The device also provides analytics on energy usage and supports integration with major smart home platforms [18]. The Sensibo Smart AC Controller provides similar features but is designed with a focus on user-friendliness and ease of installation. It utilises real-time climate-responsive adjustments by integrating seamlessly with smart home ecosystems [19].

However, both devices are engineered to function solely with individual air conditioning units, lacking the capability to integrate with heating, ventilation, or lighting systems. Therefore, while these controllers provide the advantage of remotely managing air conditioning units from virtually any location around the globe, they do not offer a comprehensive solution for overall environmental control. Their functionality is limited to air conditioning, meaning that users seeking a more integrated and scalable approach to managing multiple aspects of their indoor climate and energy usage would need to look beyond these solutions.

Thus, the project requirements were delineated to necessitate scalability and interoperability across various control units, including but not limited to fans, air conditioning systems, and heating. The solution required a high degree of modular integration, enabling seamless interaction among disparate components. Additionally, the system needed to be designed for ease of installation and maintenance. The architecture called for a centralized decision engine that integrates feedback from a diverse array of sensory modules, collectively regulating the entire HVAC system to achieve optimal performance and efficiency.

B. Lighting

Numerous research initiatives have explored various strategies to optimise lighting control systems in a manner that maximises energy savings without compromising user com-

fort. Among the most commonly deployed methods are smart key-card mechanisms, which are frequently used in hotels and similar establishments. These systems activate lighting, fans, and other utilities only when an RFID-enabled key-card is inserted into a designated holder, effectively ensuring that energy consumption is limited to periods of actual occupancy. Some variations on this approach eliminate the RFID component altogether, allowing any object placed in the key-card holder to activate utilities; while simpler and more cost-effective, this method is less secure and precise. According to Hamm [20], motion-based systems, such as those used in hotel thermostats, can significantly inconvenience guests. For instance, these thermostats often misinterpret the absence of motion during sleep as an unoccupied room, leading to the system automatically deactivating climate control. This results in uncomfortable conditions, such as guests waking up due to excessive heat, thereby undermining the intended comfort and utility of the system.

Timers represent another widely utilised solution, particularly in office environments where occupancy tends to follow predictable patterns. By automatically shutting off lighting and other utilities outside of standard working hours (typically from 8 AM to 6 PM), timers help reduce unnecessary energy consumption during off-hours.

More advanced approaches involve camera-based systems that use machine learning (ML) models to detect room occupancy and assess ambient light levels, thereby enabling dynamic and responsive lighting control. However, these systems may suffer from latency issues and present significant privacy concerns due to continuous video monitoring of occupied spaces. As Kempers [21] noted during research on camera surveillance in Western Europe:

> Moreover, surveillance is a privacy challenge in which private information is involuntarily obtained. When an entire city is under camera surveillance, the surveillance itself is not covert. However, compliance with it becomes practically involuntary for the residents. (Posner, 2008) The pervasiveness of surveillance is hard to avoid, which makes it involuntary.

Sedenberg and Chuang [22] further cement this point by noting that:

> The ubiquity of cameras with increasing resolution creates infrastructure that makes facial recognition and emotional analysis features easy additions to any surveillance system, camera-ready app, or collection of photographs.

Additionally, as Arief-Ang et al. [23] acknowledged as their motivation for building a sensor-based system instead of a camera-based system that indeed offered better accuracy:

> Unfortunately, using cameras raises privacy concerns as people do not want to be identified. Research communities have been doing their best to propose various methods to detect human occupancy without using cameras

As a result, sensor-based approaches are generally regarded as the most practical and effective for balancing energy efficiency with user comfort.

1. CO_2 sensors

The 'Room Utilisation Prediction' (RUP) method proposed by Arief-Ang et al. [23] utilises carbon dioxide (CO_2) data from Building Management System (BMS) sensors to estimate indoor human occupancy levels. Machine learning algorithms decompose and model CO_2 data to accurately predict occupancy levels in both small and large spaces. This approach supports space optimisation, HVAC control, and security monitoring while ensuring minimal infrastructure cost and operational errors. With CO_2 data alone, a 91% accuracy rate was achieved in predicting whether a room was occupied or vacant, while the accuracy for identifying the exact number of occupants was 15%. A hidden Markov model (HMM) applied to the CO_2 dataset improved the prediction of human occupancy, achieving an accuracy range of 65%–80% for up to four occupants.

Research conducted by Carroll et al. [24] to manage and understand the risk of surgical site infections by monitoring room occupancy and respiration by measuring exhaled CO_2 with infrared light sensors demonstrated that non-dispersive infrared CO_2 sensors effectively detect CO_2 in operating room conditions. Testing was conducted in a 50 m^3 operating room simulator with HEPA-filtered air supply and return ducts. Two Aeroqual 500 NDIR CO_2 sensors, positioned at the room's perimeter, measured CO_2 levels with a range of 0-5000 ppm. CO_2 levels rose proportionally with the number of occupants, their activity level, the duration of their presence, and reduced ventilation, with concentrations increasing from about 65 ppm above baseline with one occupant to approximately 300 ppm with four occupants. Although this research utilised IR sensors, the evaluation was based on the CO_2 levels measured by these sensors, leading to its inclusion in the CO_2 sensors section rather than in the subsequent IR sensors section.

2. Photodiodes and Photoresistors

Photoresistors, also known as light-dependent resistors (LDRs), are sensors that change their electrical resistance based on the amount of light they are exposed to. Typically made from cadmium sulfide (CdS) or other materials, photoresistors exhibit high resistance in darkness and lower resistance in the presence of light, making them ideal for light-sensing applications [25]. Photodiodes are semiconductor devices that convert light into an electrical current, operating on the principle of the photovoltaic effect. When exposed to light, photons generate electron-hole pairs in the semiconductor material, creating a current proportional to the light intensity [26]. Photodiodes are highly sensitive, with fast response times, making them suitable for a wide range of applications, including optical communication systems, medical instruments,

barcode scanners, and light detection in scientific instruments.

Both can be used to develop a daylight harvesting system, which, according to Vathanam et al. [27] is a system that fundamentally relies on a sensor that detects and differentiates between natural and artificial light levels within a workspace. By identifying these differences in illuminance, the system can control and balance the combined light output to achieve a desired total brightness. These sensors are typically located near occupants in the space whose lighting is being optimized, allowing the controller to fine-tune the lighting to optimise visual comfort. A notable research project by Stevens et al. [28] developed a daylight harvesting system using an intelligent lighting control system to optimise natural light utilisation and reduce energy costs in hydroponic farming. Hydroponic farming is a method of crop cultivation in nutrient-rich water, as opposed to traditional soil. The study demonstrated that over a period of 21 days, there was no significant difference in crop quality or total biomass yield; however, the system achieved an energy savings of approximately 0.72 kWh. Testing of a new Simplified Daylight Harvesting approach by Papamichael et al. [29] at their Daylighting Laboratory of the California Lighting Technology Center was also successful, with prospects of successful commercialization.

3. Ultrasonic Sensors

Stolshek et al. [30] introduced, what was then, in 1983, an innovative application of ultrasonic technology for lighting control. The system leveraged ultrasonic sensors to detect motion within a space and adjust lighting accordingly, offering a substantial reduction in energy costs while maintaining high-quality illumination. Their paper also outlined how such systems are commercially viable, and the requirements for commercial success. Yang et al. [31] also created a system in which they dimmed or increased the light emitted by LEDs depending on an object's distance from an ultrasonic sensor. This entire apparatus was also connected via Bluetooth, so a user could also manually override the brightness if required.

4. IR Sensors

Adebiiyi et al. [32] developed an automatic lighting and energy management system that utilises a Passive Infrared (PIR) sensor module with a microcontroller to optimise energy consumption by automating the control of electrical devices based on occupancy. The PIR sensor, with a detection range of 5 metres, identifies human presence through infrared radiation and transmits signals to the microcontroller, which then manages the activation of devices such as lights and fans via relay-controlled circuits. Testing of the system revealed a 15% reduction in energy consumption compared to manual control, demonstrating its energy-saving potential.

Similar research was carried out by Mouri et al. [33], who designed an automated lighting and security system that utilises Passive Infrared (PIR) motion sensors to optimise energy consumption and enhance security by detecting motion and controlling electrical loads, such as lights and alarms. PIR sensor signal was amplified by an operational amplifier and then processed by a microcontroller. The system significantly reduced energy consumption, with experimental data showing a 58.33% reduction in power usage compared to manual operation. For instance, lights that were previously on for 12 hours per day were reduced to 5 hours of operation with the integration of the PIR sensor. Simeon et al. [34] also carried out research on smart energy systems using PIR sensors in residential buildings in Nigeria. Their system also had a sensor for measuring the ambient temperature and ventured for appliance control.

III. Methods

Major Components Utilized:

- *Arduino Uno*: Powered by the ATmega 328P microcontroller, the Arduino Uno features multiple input/output pins, supporting both analogue and digital signals as well as Pulse Width Modulation (PWM). It provides stable 3.3V and 5V VCC, making it suitable for various sensor-driven applications. The platform is widely recognised for its user-friendly Integrated Development Environment (IDE) and extensive library support, facilitating easy sensor integration. Due to its versatility and accessibility, the Arduino Uno serves as an elementary microcontroller platform, frequently employed in engineering projects.
- *DHT22 (AM2302)*: The DHT22 is a digital humidity and temperature sensor that employs a polymer capacitor to measure relative humidity in the range of 0-100% and temperature between -40°C and +80°C. The sensor outputs data in digital form, providing discrete packets that can be easily read by a microcontroller. In this application, readings were taken at intervals of two seconds, although the sensor is capable of outputting data every 5 milliseconds. The DHT22 offers high-resolution measurements, with a precision of 0.1% relative humidity and 0.1°C for temperature, making it cost-effective for applications requiring precise environmental monitoring.
- *MQ135 Air Quality Gas Sensor*: The MQ135 is a gas sensor used to detect air quality by measuring the concentrations of gases such as ammonia (NH_3), nitrogen oxides (NO_x), benzene, smoke, and carbon dioxide (CO_2). It operates on a semiconductive metal oxide principle, where the sensor's resistance changes in response to the concentration of gas molecules in the environment. The sensor incorporates a heating element to maintain the optimal temperature for gas adsorption, which results in variable conductivity. This change is reflected in the sensor's analogue output, with higher gas concentrations leading to significant voltage variations. The MQ135's rapid response to changing gas concentrations makes it ideal for systems requiring active environmental monitoring.
- *HC-SR04 High-Conductance Ultrasonic Sensor*: The HC-SR04 operates by emitting high-frequency sound waves and measuring the time interval for these waves to return after reflecting off an object. It comprises two key components: a transmitter that generates ultrasonic pulses

at approximately 40 kHz (trigger pin) and a receiver that detects the reflected sound waves (echo pin). The HC-SR04 outputs a digital signal in the form of a pulse width that represents the duration of the sound wave's round trip. This pulse width, measured in microseconds, correlates directly with the distance to the object. The distance can be computed using the formula:

$$\text{Distance} = \frac{\text{Time} \times \text{Speed of Sound}}{2}$$

$$\text{Speed of Sound} \approx 343\,\text{m/s}$$

- *Proximity Infrared (IR) Obstacle Avoidance Sensor Module*: The Proximity IR sensor is designed for object detection within a range of up to 30 cm and a minimum distance of 2 cm from the sensor. It operates with a 35-degree detection span and features a transmitter and receiver. The sensor provides a digital output, emitting a LOW signal when an object is detected and a HIGH signal when no object is present. In this project, the sensor was employed to detect presence at a single entrance. When triggered, it activated the first column of lights to illuminate the room. Additionally, if entry and exit events are distinguishable, the sensor can be utilised as a counter to estimate the occupancy within a room.
- *4-Channel Isolated 5V 10A Relay Module with Optocoupler*: This relay module is designed to control high-current and high-voltage appliances, with each relay capable of handling up to 10A at 250V AC or 30V DC. It features safety indicators for power and control status, ensuring reliable operation. The optocoupler facilitates interaction between devices with different grounds, providing electrical isolation for safety while enabling functional integration. This module is integral to the project for interfacing with conventional switchboards, providing AC support, and allowing independent battery power for fans and LEDs to prevent overloading the Arduino.
- *Light-Emitting Diodes (LEDs)*: LEDs, available at a cost of less than one rupee, are used for illumination within the project.
- *DC Motor and Fan*: The DC motor, operating within a standard voltage range of 3-6V, drives the fan blades, achieving a rotational speed of approximately 11,000 RPM. This speed is more than adequate for the simulation requirements of the project.
- *Batteries*: The project utilises 3.6V, 2600 mAh batteries to power the LEDs and fans, providing sufficient energy for operation while ensuring optimal performance.
- *ATmega 328P Microcontroller*: The ATmega 328P is an 8-bit RISC microcontroller renowned for its efficiency and low power consumption, making it suitable for embedded applications. It employs Harvard architecture, which features separate memory spaces for instructions and data, enhancing execution speed through parallel access. It has both analogue and digital GPIO pins. These I/O functions are managed by the Data Direction Registers (DDR), which determine the pin configuration as input or output. The ATmega 328P supports communication protocols including UART, SPI, and I2C, facilitating integration with additional peripherals if required for more advanced system designs.
- *16 MHz Crystal Oscillator*: It operates on the piezoelectric effect of quartz, which vibrates at a fixed frequency when an electric voltage is applied. Its advantages include high stability, accuracy, and minimal jitter, which are critical for timely activation of lighting and fans in response to sensor data. However, drawbacks include its fragility, cost, longer start-up time, and increased PCB space requirements.
- *Various Capacitors and Resistors*: Capacitors are essential for stabilising the crystal oscillator's operation by providing necessary grounding. Resistors are employed in voltage divider circuits and other electronic applications to ensure appropriate voltage levels and circuit functionality.
- *LM7805 Voltage Regulator*: The LM7805 is a 5V voltage regulator used to step down input voltage, providing a stable 5V output required for powering the ATmega 328P microcontroller and ensuring consistent operation of the embedded system.
- *LCD*: A two-line Liquid Crystal Display was used to display some sensor outputs.

A. Prototype 1

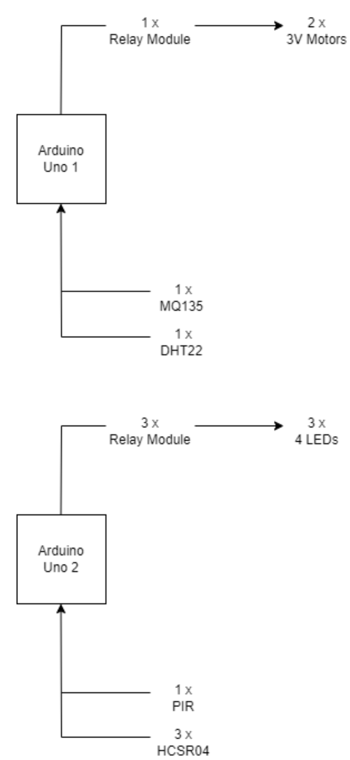

Fig. 1: Simplifed Block Diagram

Prototype 1 served as a preliminary feasibility assessment for the project's concept. A breadboard was used to set up three distinct columns of LEDs, with each column consisting of four LEDs connected in parallel. Each LED column was controlled individually by separate relay modules, which were connected to the LEDs on the breadboard. Both the input and output controls were managed via an Arduino microcontroller, which was programmed with specific threshold conditions to activate the three relay modules. These modules, in turn, powered the LEDs from an attached battery. The battery was necessary as the Arduino was not able to power the LEDs very well as each LED requires 20 milliamperes of current for optimum luminous output.

The setup included an ultrasonic sensor, which was programmed to activate the first column of LEDs. Similarly, the subsequent columns were triggered by additional ultrasonic sensors, each corresponding to its respective column. Additionally, the first column of LEDs was also activated by a Proximity Infrared (PIR) sensor, whose future use was to act as a counter to estimate the total population in the room if entry and exit were not made through the same door.

The fan components were mounted on motors, with both motors controlled by a dedicated relay module, distinct from the fourth unused relay in the 4-relay module. This fan relay module was powered by a separate battery, as each motor requires approximately 800 milliamperes to operate efficiently. Fan activation was managed by a secondary Arduino that responded to data from the DHT22 sensor, which monitored temperature, and the MQ135 sensor, which assessed air quality. Specifically, the fan was triggered when the temperature exceeded 30°C or when the air quality readings surpassed 60 ppm.

B. Prototype 2

In this version, the Arduino Uno was replaced with a standalone ATmega328P, retaining the same functionality and thresholds. The system activates fans based on temperature and pollutant levels, and LED columns upon sensor detection. A 16 MHz crystal oscillator connected to XTAL1 and XTAL2 pins ensures precise timing for the ATmega 328P by stabilising oscillations with capacitors. The ATmega was programmed using the Arduino IDE. Batteries power the LEDs and fans through relays, and sensor inputs connect to the microcontroller via pins on the PCB. The wiring colour scheme is: yellow for sensor inputs, black for grounding, red for +5V, and blue for relay triggering. The system requires a DC input voltage of 12V to 20V.

Several initial errors occurred during circuit development. The voltage regulator was incorrectly placed, and improper grounding led to malfunctions, as certain components required high-value resistors for proper grounding. Furthermore, the relay module's wires were soldered incorrectly, causing short circuits. Initial attempts to program the ATmega microcontroller were made without using the crystal oscillator. Confusion between the MQ135 sensor's digital and analogue output pins also caused issues, as digital pins cannot handle analogue signals. Although the 5 picofarad capacitors seemed trivial, they were crucial for filtering out minor electrical noise.

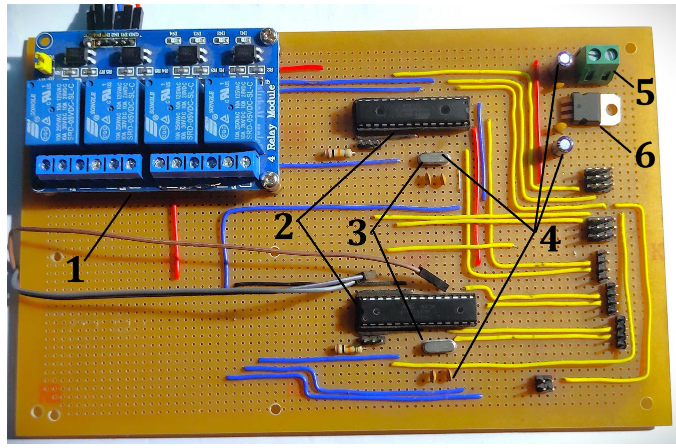

Fig. 2: Final circuit

No. in Fig. 2	Component
1	4-channel Relay module
2	2 x ATmega 328P
3	16 MHz crystal oscillator
4	Capacitors, 5pF and 100μF
5	Input Power Source
6	Voltage Regulator

Table 1: Circuit Configuration

Sensors, fans, and motors were mounted onto a cardboard enclosure to simulate a real room environment. The Proximity IR sensor was positioned at the entrance to activate the initial set of columns upon detection of a human figurine entering through the door cutout. Due to spatial constraints, both the IR sensor and the initial ultrasonic sensor controlled the same lighting column. As the person moved within the room, different columns of lights were sequentially activated, remaining illuminated while the ultrasonic sensor continued to detect the presence of the person.

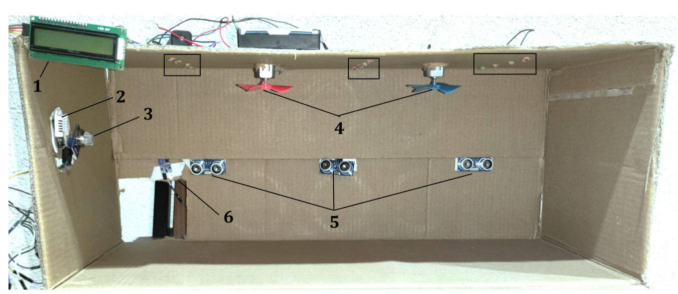

Fig. 3: A small-scale simulation of a room

No. in Fig. 3	Component
1	LCD screen
2	DHT22
3	MQ135
4	Fans
5	HCSR04
6	Proximity IR
Boxes	Columns of LEDs

Table 2: Simulation Configuration

Fig. 4: Sample LCD Output

In this context, 'H' represents the Relative Humidity, while 'T' denotes the temperature of the simulated environment, expressed in degrees Celsius. The 'HI' refers to the Heat Index, which provides an estimation of the perceived temperature by factoring in the humidity level. Finally, 'AQ' stands for Air Quality, measured in parts per million (ppm), indicating the concentration of specific pollutants within the environment.

IV. Results and Future Research

The results were encouraging, with minimal latency observed between the sensor detection and the relay pin being triggered by the ATmega. Without the system in place, the battery pack used to power the fans and LEDs discharged completely in approximately 65 minutes. However, when using a Hexbug Nano to simulate random movement and triggering the MQ135 sensor by spraying mosquito repellent at it at regular 8-minute intervals, the battery lasted around 105 minutes. This is nearly a 61% increase, which shows both the efficiency and efficacy of the system. Demonstrative videos, code with instructions, and soldering connections have been made available in [37].

Further simulations would be advantageous, particularly with the addition of three more ultrasonic sensors to establish a 9-point grid, allowing for individual LED activation based on the detected coordinates. This improvement is one of the planned future enhancements. The primary focus, however, is to make the entire system wireless. The relay pins provide up to 10A at 250V AC to the appliances, which supports system expansion. Future plans involve utilising a Raspberry Pi as the decision engine, with each module featuring a sensor, a Wi-Fi/Bluetooth module for communication, and an ATmega to process and relay sensor data. This would allow the creation of a highly adaptable, easy-to-install system capable of integrating into any environment, regardless of size, layout, or appliance type.

The move from Arduino to ATmega was driven by the need for a more scalable and modular architecture. This design would enable integration into any system, as long as a switchboard is present, offering flexibility and scalability across diverse applications.

V. Conclusion

While numerous market solutions exist for HVAC regulation featuring advanced functionalities such as web connectivity, allowing remote access and modification from anywhere globally, and integration with AI assistants like Siri or Alexa for voice activation and behavioural learning, these systems rely primarily on centralised control architectures. Existing decentralised systems are typically limited to individual units and are incapable of regulating an entire space comprehensively, focusing solely on the utility they are integrated with. This limitation is particularly relevant in low-to-middle-income developing nations, such as India, where decentralised systems are more prevalent. Major companies like Havells and Syska are developing smart switchboards; however, their solutions do not accommodate utilities such as air conditioners, air purifiers, or heaters, nor are they optimised for energy efficiency. They currently offer features like voice-activated switches and remote on/off control, which this project also aims to offer in the future. Camera-based lighting control systems have various limitations, making sensor-based solutions more suitable. In conclusion, this research has explored the feasibility of developing an adaptive HVAC and lighting energy-saving system that can integrate with decentralised systems, yielding promising results. The next phase involves transitioning the system to a fully wireless configuration and conducting tests in a real-world environment.

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